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Denneulin et al.

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(54) **ADAPTIVE SIGNAL CUSTOMIZATION**

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(22) Filed: **May 27, 2016**

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H04R 29/00	(2006.01)
H04R 3/04	(2006.01)

(52) **U.S. Cl.**

CPC ***H04R 3/04*** (2013.01); *H04R 2201/028* (2013.01)

(58) **Field of Classification Search**

CPC H04R 3/04; H04R 7/045; H04R 2201/028; H04R 2499/11; H04R 2499/15

USPC 381/100

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,298,141	B1	10/2001	Hickman	
6,304,435	B1 *	10/2001	Hsu	G06F 1/1616 345/905
6,417,659	B1	7/2002	Schroeder	
7,447,332	B2	11/2008	Harris, Jr. et al.	
8,189,809	B2	5/2012	Aarts	
2008/0298608	A1 *	12/2008	Wilcox	H03F 3/20 381/120
2012/0121117	A1 *	5/2012	Kim	H04M 1/03 381/334

FOREIGN PATENT DOCUMENTS

WO	00/02417	A1	1/2000
WO	2009/113016	A1	9/2009

* cited by examiner

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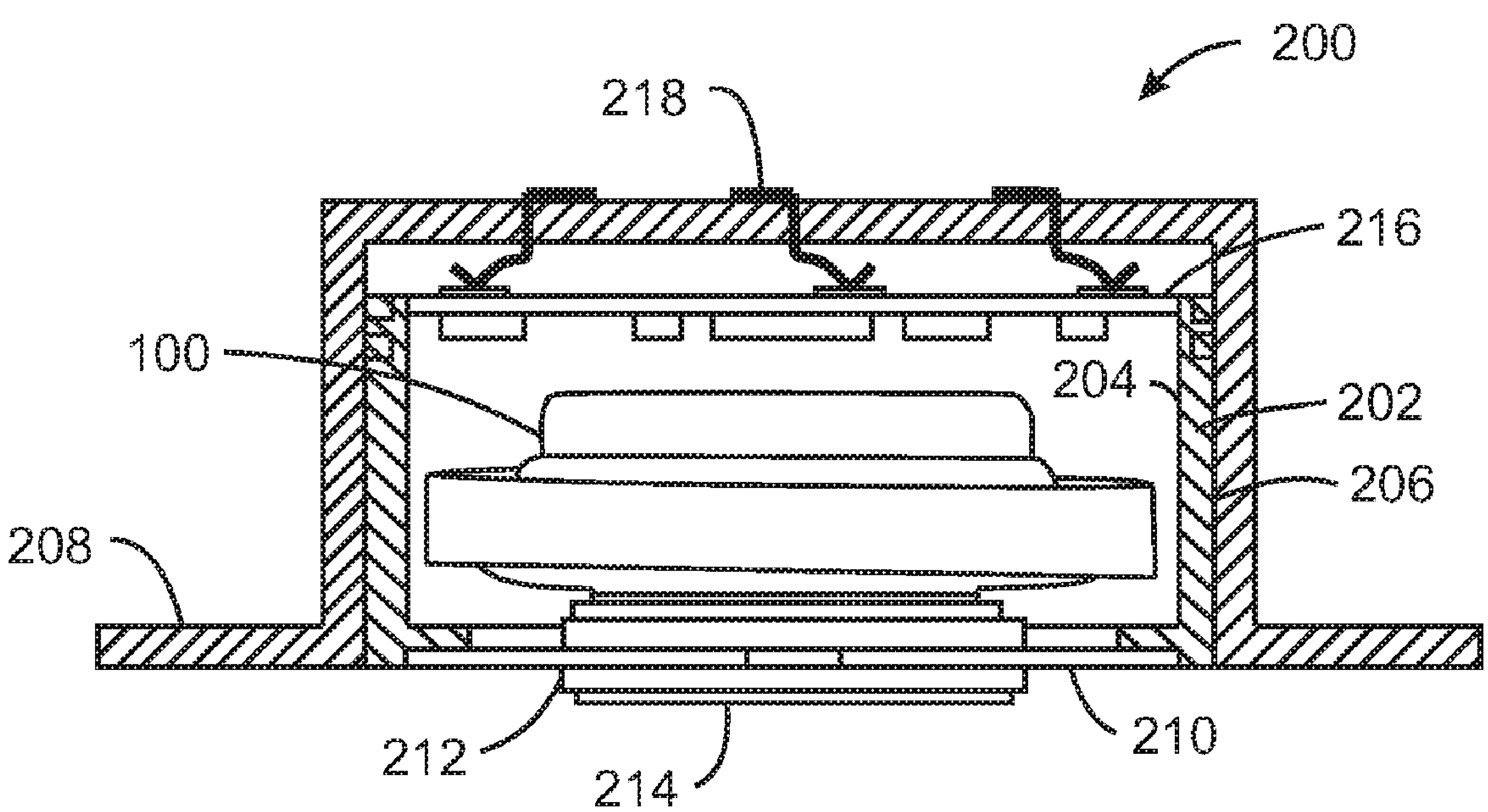
(57) **ABSTRACT**

An exciter device for transmitting vibration to a support is described. The exciter device comprises a housing, wherein a portion of the housing comprises an interior surface and an exterior surface, the interior surface disposed inside the housing and the exterior surface disposed outside the housing. An exciter is disposed on the interior surface. A rubber suspension is integrated into the portion of the housing. A printed circuit board comprising an amplifier forms a top of the exciter device.

21 Claims, 8 Drawing Sheets



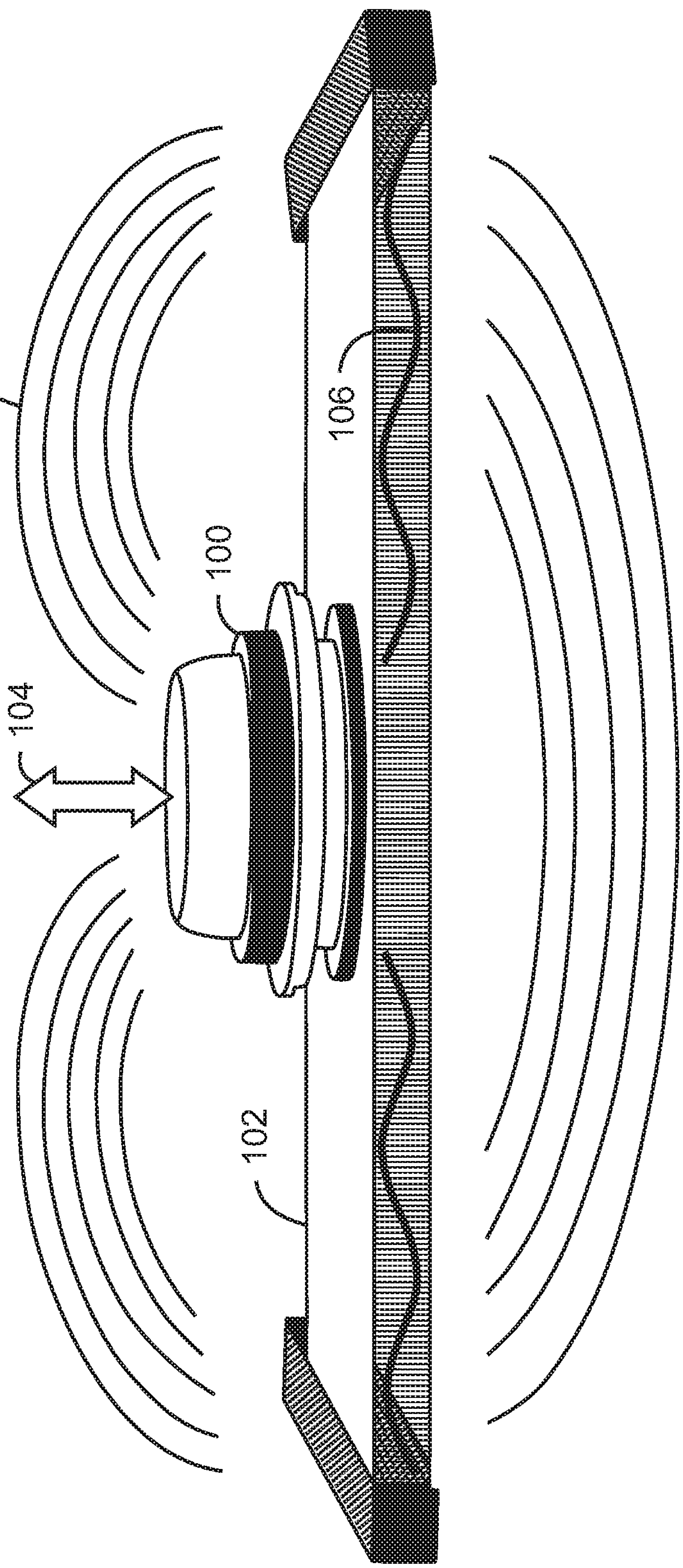


FIG. 1

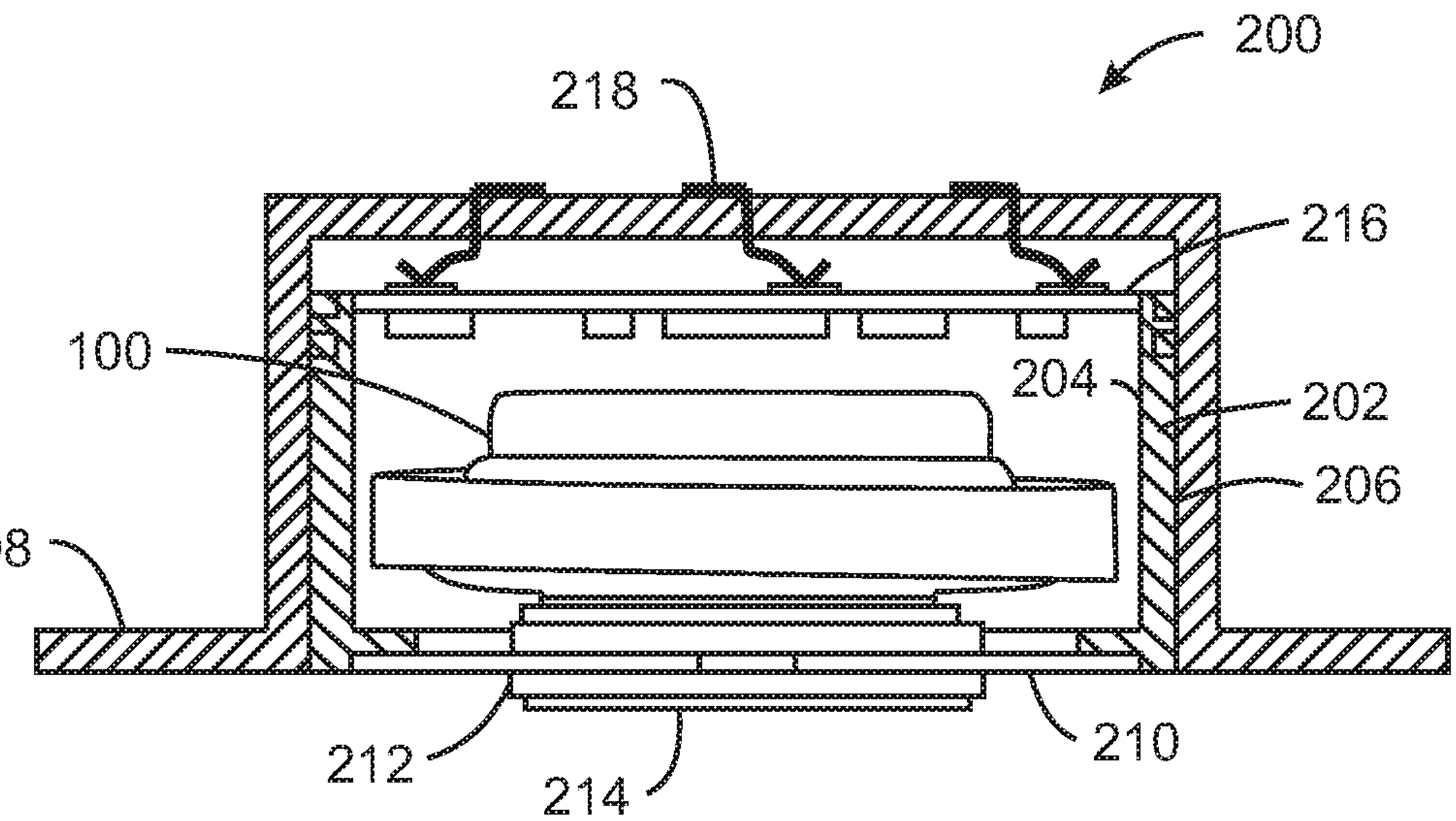


FIG. 2

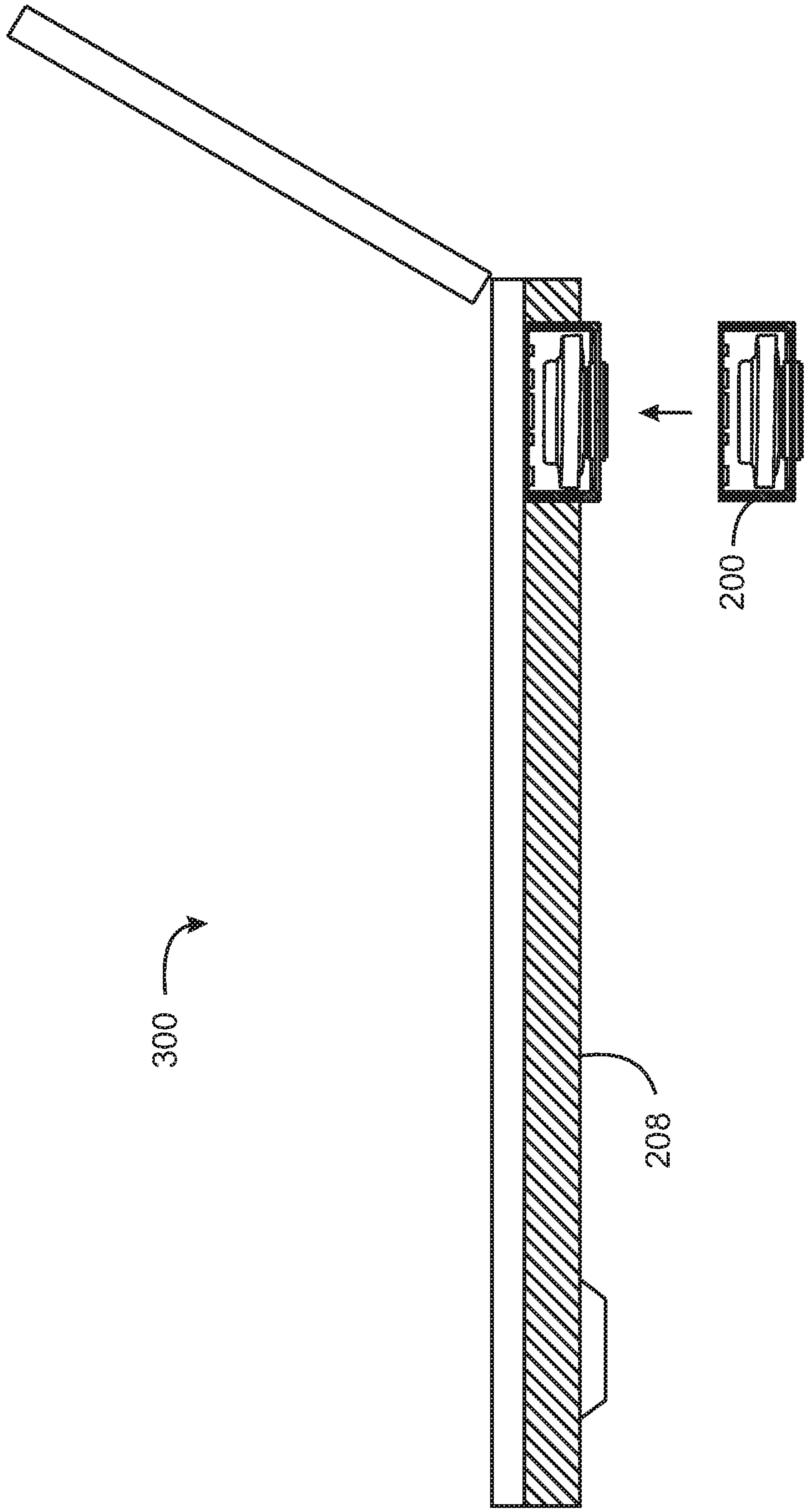


FIG. 3

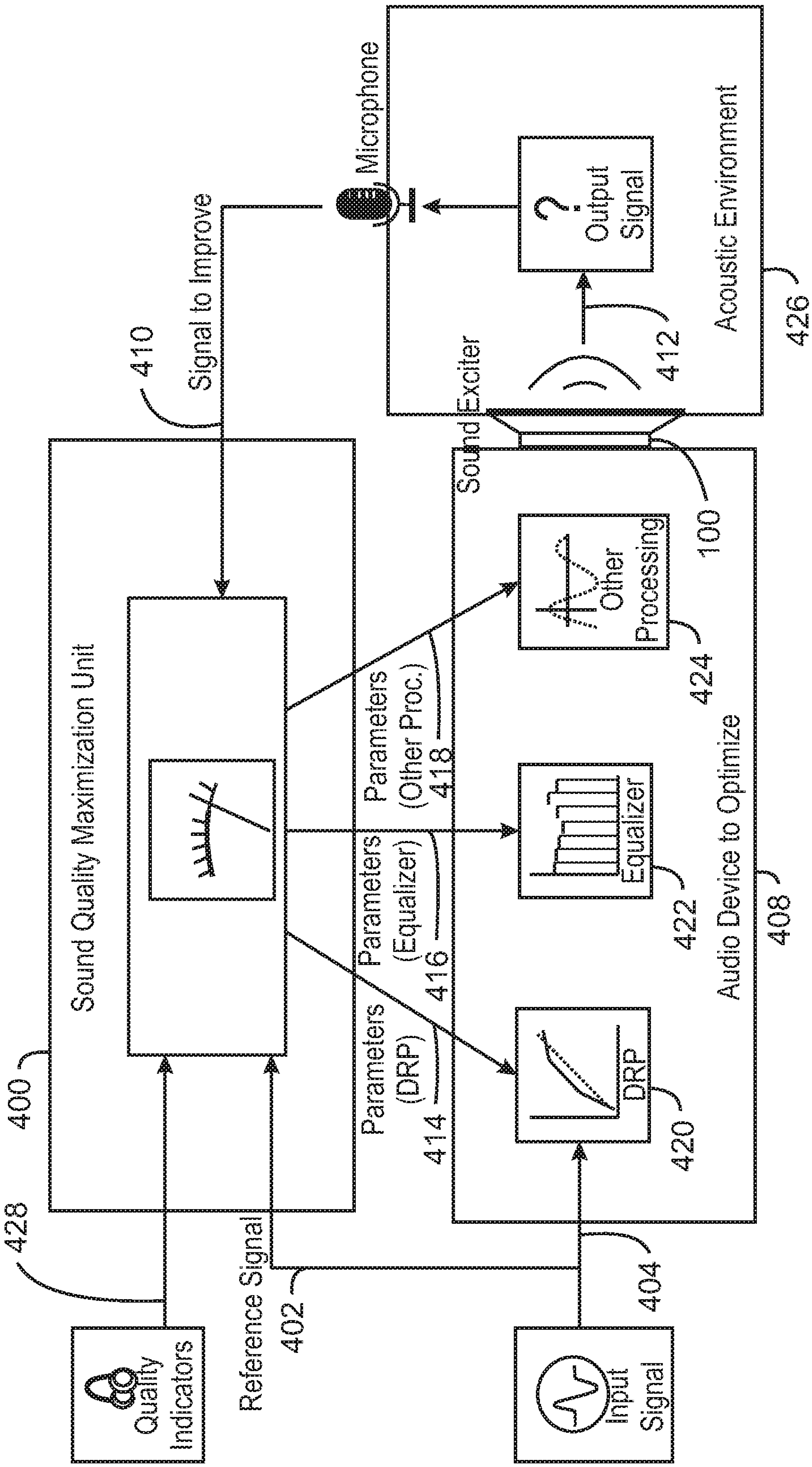
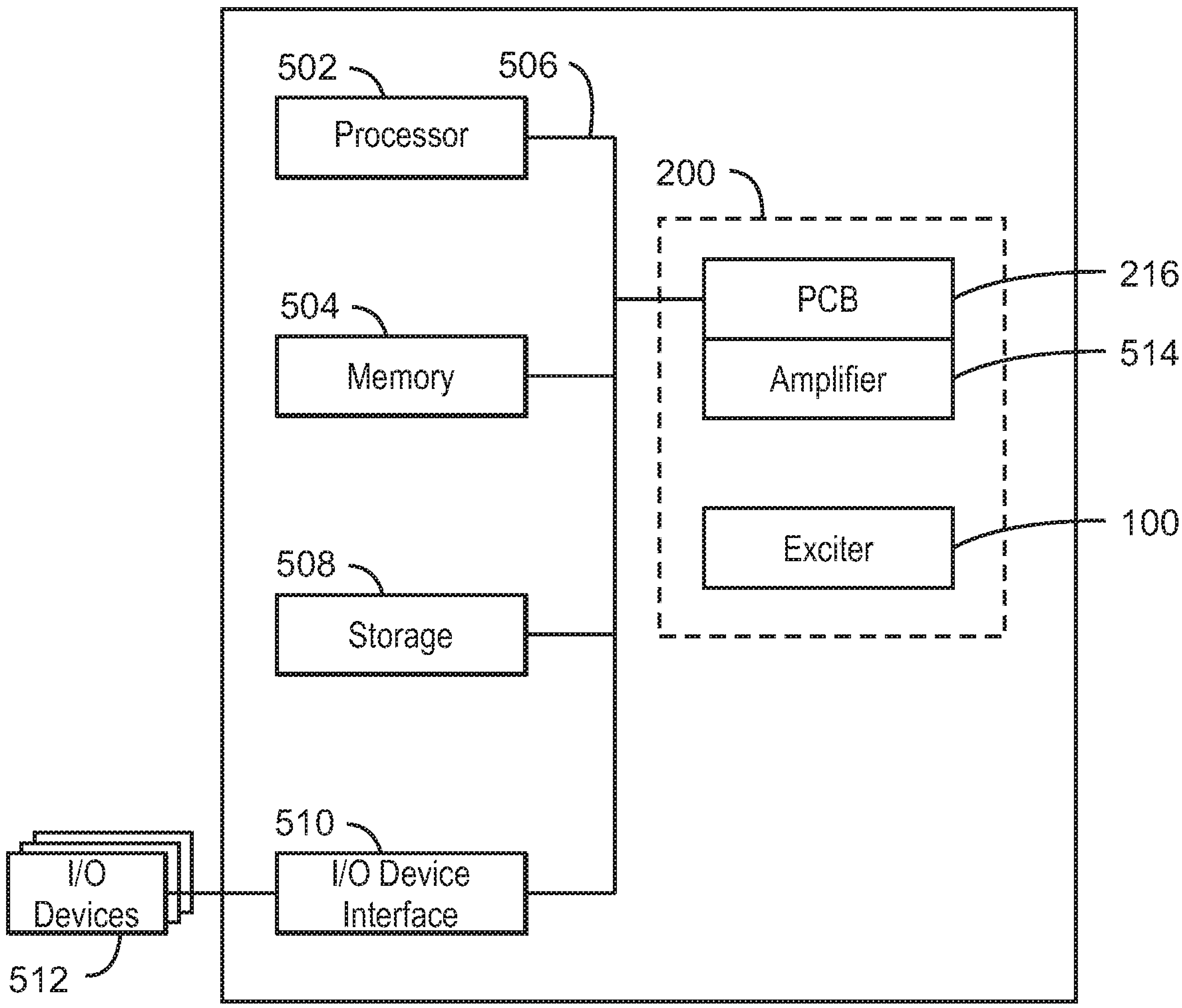
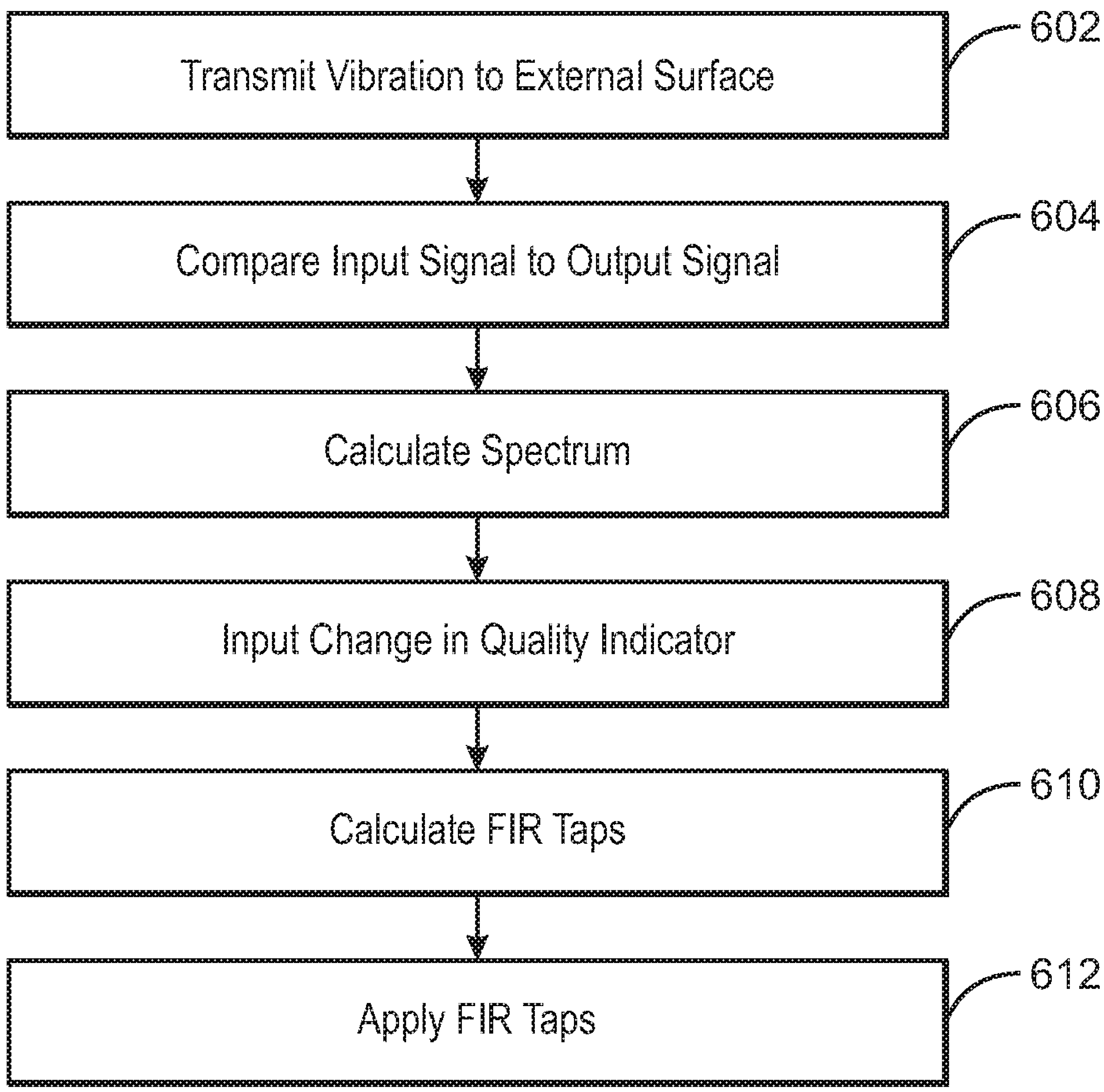

Sound Quality Maximization Unit
400
Signal to Improve
410
Microphone
Output Signal
412
Acoustic Environment
426
Sound Exciter
100
Parameters (DRP)
414
Parameters (Equalizer)
416
Parameters (Other Proc.)
418
DRP
420
Equalizer
422
Other Processing
424
Audio Device to Optimize
408
Quality Indicators
428
Reference Signal
402
Input Signal
404

FIG. 4


502
506
Processor
200
PCB
216
Amplifier
514
504
Memory
Exciter
100
508
Storage
510
I/O Devices
I/O Device Interface
512

500

FIG. 5


Transmit Vibration to External Surface
602
Compare Input Signal to Output Signal
604
Calculate Spectrum
606
Input Change in Quality Indicator
608
Calculate FIR Taps
610
Apply FIR Taps
612

600

FIG. 6

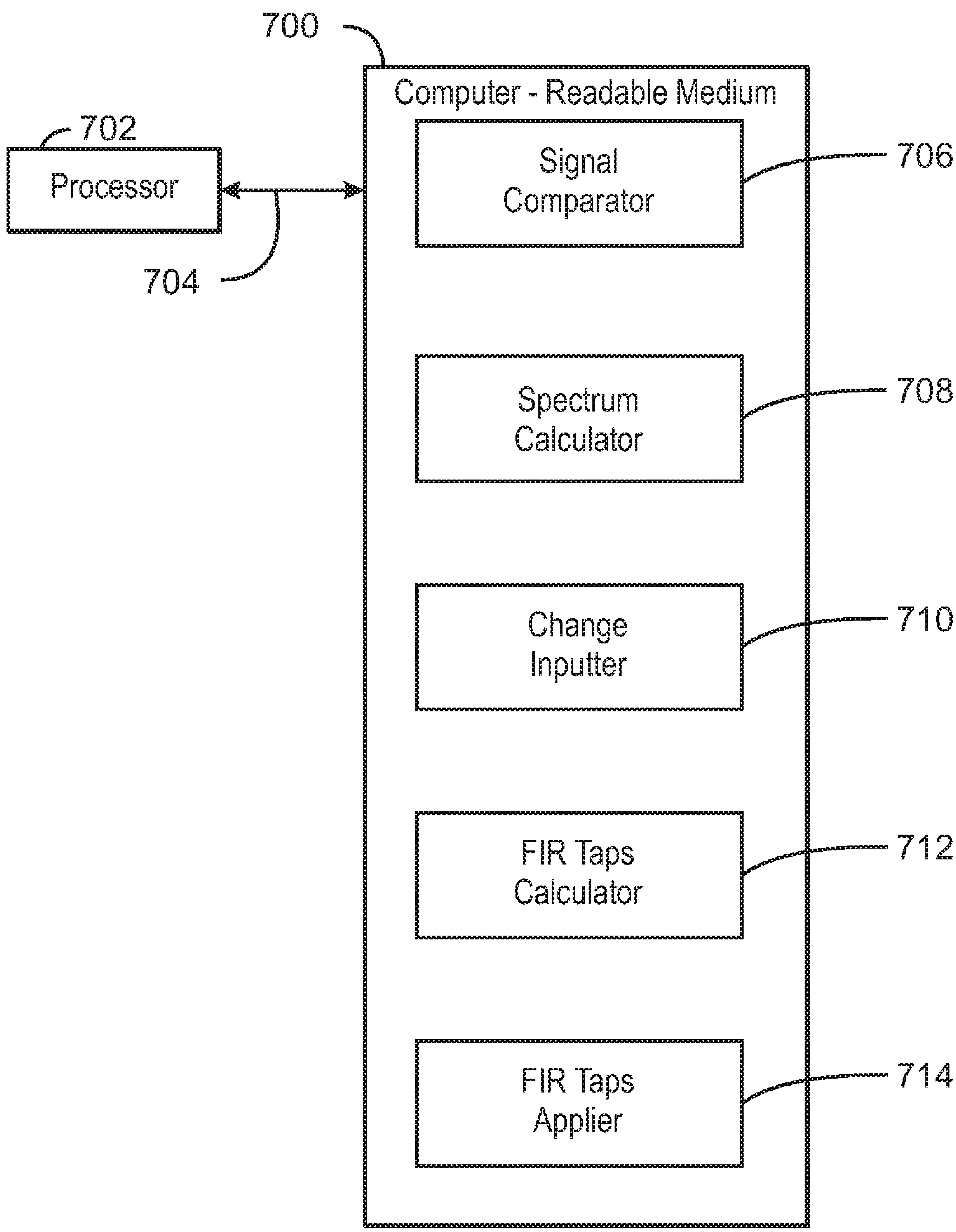

700
Computer - Readable Medium
702
Processor
704
Signal Comparator
706
Spectrum Calculator
708
Change Inputter
710
FIR Taps Calculator
712
FIR Taps Applier
714

FIG. 7

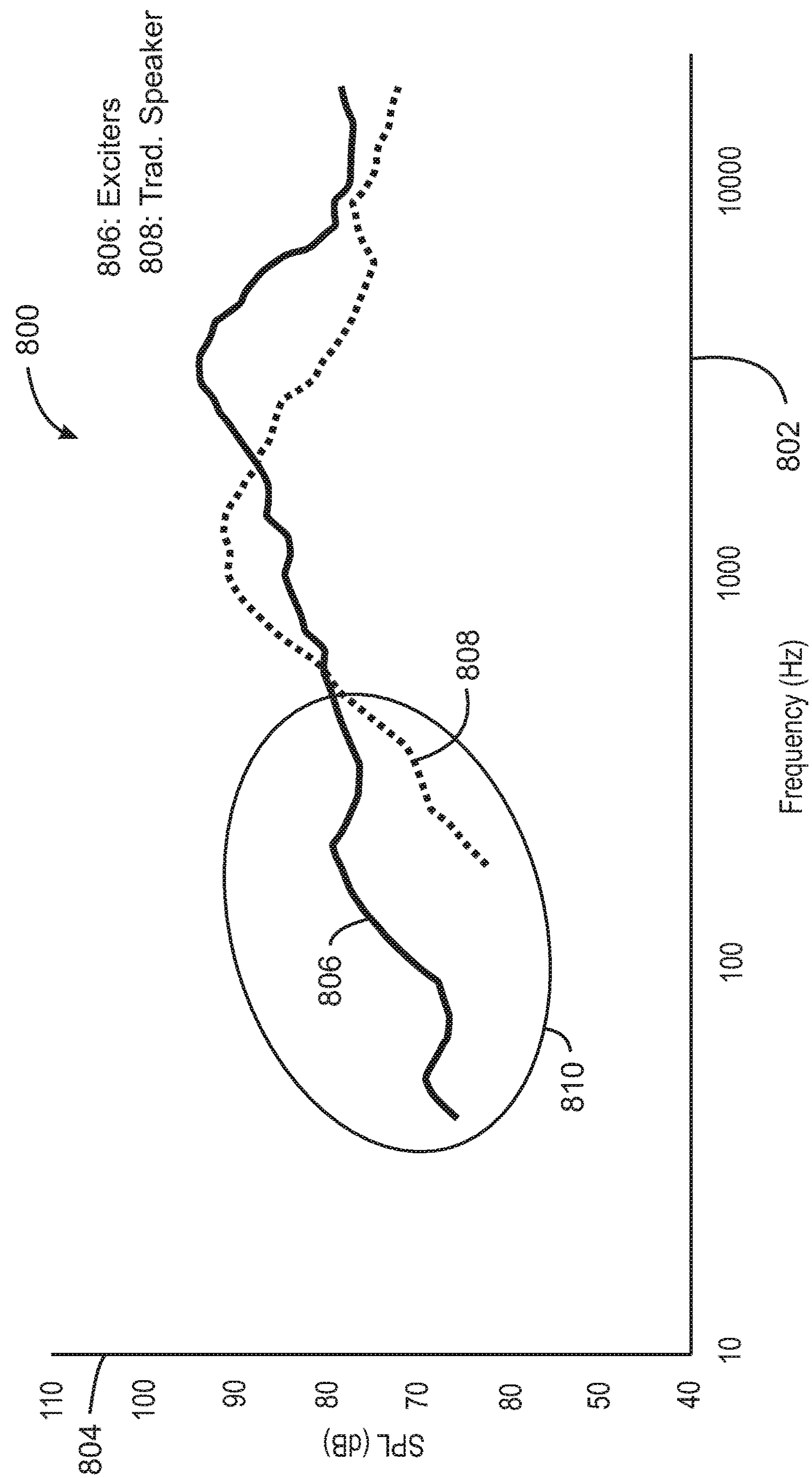

800
806: Exciters
808: Trad. Speaker
SPL (dB)
110
100
90
80
70
80
50
40
804
10
100
1000
10000
Frequency (Hz)
802
806
808
810

FIG. 8

ADAPTIVE SIGNAL CUSTOMIZATION

BACKGROUND ART

Powerful low frequency sound waves are most often produced by electrodynamic loudspeakers using a large diaphragm to provide the required volume displacement and enough mass to resonate at low frequencies. The large diaphragm can be provided by loudspeakers in the audio device itself. The loudspeakers embedded in portable devices, e.g., laptops, tablets, and smart phones, are usually small. As a result, the loudspeakers' diaphragms are small as well and the resonance frequency is relatively high. A consequence is that the system's low cut-off frequency is mostly above 400 Hz. This high pass cut-off frequency results in the inaudibility of most low frequencies.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram showing how an exciter works to produce sound waves.

FIG. **2** is a transverse view of an exciter device for transmitting vibration to a support surface.

FIG. **3** is a diagram showing the integration of the exciter device into the bottom cover housing of a laptop.

FIG. **4** is a block diagram depicting how the sound quality maximization unit functions.

FIG. **5** is a block diagram of an audio device for adaptive signal customization.

FIG. **6** is a process flow diagram of a method for the adaptive customization of an audio signal.

FIG. **7** is a block diagram showing a medium that contains logic for the adaptive customization of an audio signal.

FIG. **8** is an example according to the present techniques.

The same numbers are used throughout the disclosure and the figures to reference like components and features. Numbers in the **100** series refer to features originally found in FIG. **1**; numbers in the **200** series refer to features originally found in FIG. **2**; and so on.

DESCRIPTION OF THE EMBODIMENTS

The subject matter disclosed herein relates to techniques for the adaptive customization of audio signals. The present disclosure describes techniques for adaptive signal customization that use an exciter to transmit mechanical vibrations to a surface external to a computing device. In embodiments, the quality of the sound produced may depend on the mechanical properties of the support. However, an algorithm for sound quality maximization can be used to ensure quality sound over a broad range of frequencies.

A sound quality maximization unit uses the mechanical properties of the support and changes in quality indicators (input by the user) to compute parameters for the different algorithms in the audio processing chain. The sound quality maximization unit sends the updated parameters to each processing block in the audio chain. For example, the sound quality maximization unit may include an equalizer that may be adapted to provide varying audio output by applying parameters to a finite impulse response (FIR) filter, where the equalizer is part of a computing device that includes an exciter. The audio signal input to the audio device may be compared to the audio signal output by the audio device. The output audio signal may be determined by analyzing the acoustic environment and the computing device that includes the exciter. Based on the comparison of the input and output signals, a spectrum of the computing device combined with a spectrum of the acoustic environment may be calculated. FIR taps may be calculated such that the FIR filter has a frequency response that is the inverse of the spectrum of the computing device combined with the spectrum of the acoustic environment. The parameters used to adapt the equalizer may be based, at least in part, on the FIR taps. In response to the FIR taps, the equalizer may flatten the spectrum of the input audio signal. If a user of the computing device prefers an audio response that is not flat, the user may input a preference by changing a sound quality indicator. The change in the sound quality indicator may be taken into account during the computation of the FIR taps. The process described above may be repeated after the equalizer is adapted by applying parameters to an infinite impulse response (IIR) filter. The result may be an output audio signal that is very close to the sound quality wanted by the user, which is generally a high quality signal independent of the acoustic environment. Various examples of the present techniques are described further below with reference to the figures.

In the following description and claims, the terms "coupled" and "connected," along with their derivatives, may be used. It should be understood that these terms are not intended as synonyms for each other. Rather, in particular embodiments, "connected" may be used to indicate that two or more elements are in direct physical or electrical contact with each other. "Coupled" may mean that two or more elements are in direct physical or electrical contact. However, "coupled" may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other.

FIG. **1** is a diagram showing how an exciter works to produce sound waves. The exciter **100** is disposed on a support surface **102**. The exciter vibrates as indicated by arrow **104**. The mechanical vibration of the exciter is transmitted to the surface **102** and causes the surface **102** to vibrate mechanically as indicated by the wavy lines **106**. The vibrating surface produces sound waves **108**. In embodiments, the sound waves **108** represent the audio output of the exciter.

In particular, the size of the surface **102** is directly related to the frequency range of the sound waves produced by the surface **102** when subjected to vibrations from the exciter. When the surface is relatively large, low frequency sound waves are produced. When the surface is relatively small, higher frequency sound waves result. As used herein, the relative size of the surface **102** is determined by the relationship between the size of the surface **102** and the size of the exciter **100**.

FIG. **2** is a transverse view of an exciter device **200** for transmitting vibration to a support surface. The exciter device **200** may include a pot or housing **202**. A portion of the housing **202** may include an interior surface **204** and an exterior surface **206**. The interior surface **204** may be disposed inside the housing **202** and the exterior surface **206** may be disposed outside the housing **202**. The housing **202** may be disposed in the bottom cover housing **208** of a computing device (not shown).

An exciter **100** may be disposed on or within the interior surface **204** of the housing **202**. The exciter **100** may be the exciter shown in FIG. **1**. A rubber suspension **210** may be integrated into the portion of the housing **202**. In embodiments, the rubber suspension **210** is to attach the exciter **100** to the housing **202**. The rubber suspension **210** is to mechanically decouple the exciter **100** from the remainder of the computing device (not shown). Because of the mechanical decoupling, the exciter **100** may only transmit vibration to the surface supporting the computing device and not to the computing device itself. This may prevent the introduction of unwanted vibration. In embodiments, the rubber suspension **210** may absorb vibrations from the exciter **100**, thereby preventing the transfer of vibration to the housing **202** and the bottom cover housing **208** of a computing device. While the rubber suspension **210** has been described as preventing the transfer of vibration to a computing device including the exciter device **100**, any vibration mitigation techniques may be used. For example, the exciter device **100** may be coupled with the housing **202** via a plurality of springs.

A foot **212** may be attached to the rubber suspension **210**. In embodiments, the foot **212** may be plastic or any other suitable material. An anti-skid surface **214** may be attached to the foot **212**. The anti-skid surface **214** of the foot **212** may prevent movement of the foot **212** and prevent unwanted vibration.

A printed circuit board (PCB) **216** may form the top of the housing **202**. The PCB **216** may include electronics dedicated to the exciter **100**. The PCB **216** may include an amplifier that produces an amplified audio signal that causes the exciter **100** to vibrate. Alternatively, the PCB **216** may be part of the computing device itself (not shown). In such an embodiment, the housing includes a top portion that is to receive an audio signal that is to cause the exciter **100** to vibrate.

As illustrated in FIG. **2**, spring contact **218** may have one end disposed on the PCB **216** and a second end disposed on the bottom cover housing **208** of the computing device (not shown). The spring contract **218** may electronically couple the exciter device **200** to the computing device (not shown). The spring contact **218** may enable the exciter device **200** to be plugged into and unplugged from the computing device (not shown).

FIG. **3** is a diagram showing the integration of the exciter device **200** into the bottom cover housing **208** of a computing device **300**. A clip mechanism (not shown) may hold the exciter device **200** in place when the exciter device **200** is inserted into the bottom cover housing **208**. The clip mechanism (not shown) may make it easy to insert and remove the exciter device **200**. The clip mechanism (not shown) may cooperate with a spring contact **218** (not shown) to electrically connect the exciter device **200** to the computing device **300** and maintain electronic compatibility between the exciter device **200** and the computing device **300**. The mechanism that holds the exciter device **200** within the computing device **300** is not limited to a clip design. Several types of retaining means will do. For example, the exciter device **200** may have protrusions that fit into complementary holes in the bottom cover housing **208**. As a result, the exciter device **200** may include a retention feature that is to couple with a retention feature of the computing device **300**.

The spring contacts **218** of the exciter device **200** may enable communication between hardware and software of the computing device **300** and the exciter device **200**. The computing device **300** may include a sound card, an audio digital signal processor (DSP), and other hardware. This hardware may include an analog-to-digital converter, which takes the analog input audio signal and converts it to a digital signal. The DSP may capture the digitized information and begin processing the information. The signal may be transferred via the spring contracts **218** to the PCB **216** dedicated to the exciter device **200**. The PCB **216** may include audio processing circuitry (e.g., an equalizer) for processing of the digital signal by the sound quality maximization unit. The PCB **216** may also include a digital-to-analog converter, which converts the signal back to an analog signal. The analog sound signal may be amplified by an amplifier associated with the PCB **216**. The analog sound signal output by the amplifier causes the exciter to vibrate. This in turn causes the production of sound waves by the surface supporting the computing device **300** as the vibrations are transferred from the exciter to the surface. In some embodiments, the PCB **216** and the amplifier may be part of the computing device itself. In these instances, it is especially important that the spring contacts **218** maintain the electronic connection between the exciter device **200** and the computing device **300**.

The power of the amplifier associated with the PCB **216** is measured in Watts. Different types of computing devices, e.g., laptops, tablets, and smart phones, may have different wattage amplifiers. Larger devices may have larger wattage amplifiers, while smaller devices may have smaller wattage amplifiers. Larger wattage amplifiers may require larger exciters **100**, while smaller wattage amplifiers may require smaller exciters **100**. An exciter **100** may be described by the wattage of the corresponding amplifier. For example, the exciter **100** in the computing device **300** may be a 10 W exciter.

In embodiments, the computing device **300** may be purchased with one of its rubber feet replaced by an exciter device **200**. Rubber feet are typically installed on computing devices that are to be positioned on top of a support surface. However, the cost of the computing device **300** may increase because of the added cost of the exciter device **200**. Alternatively, the computing device **300** may be sold without the exciter device **200** and the exciter device **200** may be sold separately. In such an embodiment, the rubber feet are removable so that they can be replaced with an exciter device **200**.

FIG. **4** is a block diagram depicting how the sound quality maximization unit **400** functions. A reference signal **402** may be input to the sound quality maximization unit **400**. The reference signal **402** may be the same as the input signal **404** to the audio device **408** being optimized. In embodiments, the input signal **404** and the reference signal **402** are obtained from an audio file which may be stored on the computing device, streamed to the computing device via a network, or obtained from a computer readable media. A signal to improve **410** may also be input to the sound quality maximization unit **400**. The signal to improve **410** may be the same as the output signal **412**. The signal to improve **410** may be used as a feedback signal to the sound quality maximization unit **400**. The quality of the output signal **412** may be determined by the sound waves produced in response to the vibration of the exciter **100**. The sound waves produced are determined by the mechanical properties of the surface supporting the audio device **408**. In this fashion, the mechanical properties of the surface supporting the audio device **408** ultimately affect the quality of the output signal **412**/signal to improve **410**. The sound quality maximization unit **400** may compare the reference signal **402** to the signal to improve **410** and take into account the quality indicators **428** to compute parameters **414**, **416**, **418** for the different algorithms in the audio processing chain. The sound quality maximization unit **400** may send the updated parameters **414**, **416**, **418** to each processing block **420**, **422**, **424** in the audio chain.

In embodiments, a dynamic range processor (DRP) may be used to alter the input signal **404** by maximizing the dynamic range. The dynamic range is the ratio of the loudest to the weakest sound intensity produced by the audio device. Dynamic range is subjective, with each user possibly desiring a different range for quality sound. Thus, based on their preference, users can adjust the dynamic range of the audio device to achieve the desired target response as illustrated by the DRP graph **420**.

Additionally, the equalizer **422** may have its parameters **416** updated by the sound quality maximization unit **400** as follows. The equalizer **422** may function as a finite impulse response filter (FIR). An FIR filter is a filter whose impulse response is of finite duration, i.e., the impulse response settles to zero in finite time. By subtracting the reference signal **402** from the output signal **412**, the sound quality maximization unit **400** calculates a frequency spectrum of the audio device **408** (including the exciter **100**) combined with the frequency spectrum of the acoustic environment **426**. The acoustic environment **426** is the environment in which the audio device **408** is located. The sound quality maximization unit **400** may compute FIR taps such that the equalizer **422** has a frequency response that is the inverse of the spectrum of the audio device **408** combined with the spectrum of the acoustic environment **426**. FIR taps are coefficients in the mathematical equation for the filter constituting the equalizer. The sound quality maximization unit **400** may send the new parameters **416**, i.e., FIR taps, to the equalizer **422**.

In response to the new parameters **416**, the equalizer **422** may boost certain frequency bands or attenuate other frequency bands. The result may be a flattened spectrum. A flattened spectrum may have a graph that is relatively flat and smooth indicating a similar amount of power in all frequency bands from 20 Hz to 20 kHz. If a user prefers an audio response that is not flat, the user may input his preference by changing a quality indicator **428**. A quality indicator **428** may indicate the quality of a plurality of characteristics of the sound output by the system. For example, a quality indicator **428** may indicate how much bass is present in the output signal. If a user wishes to change the amount of power to the base frequencies, he may change the setting of a quality indicator **428** accordingly. The change in the sound quality indicator may be taken into account during the computation of the FIR taps. Settings of a quality indicator, as used herein, may include but are not limited to tonal balance (including bass, midrange, and treble tones), the dynamic range of the audio system, output power of the audio system, phase control, noise, distortion and frequency response.

The sound quality maximization unit may also use other parameters **418** and additional processing **424** to maximize the output signal **412**. Other parameters include, but are not limited to, amplification of the audio signal, amplitude/frequency response, distortion, non-linear distortion, noise, and the like. Additional processing **424** can use parameters **418** to mitigate any undesirable components of the audio output. For example, a neural network may be used to maximize the output signal **412** by suppressing noise.

The sound quality maximization unit **400** may repeat the process for the adaptive customization of an audio signal with the equalizer **422** functioning as an infinite impulse response (IIR) filter alone or in combination with an FIR filter. The process is repeated to further improve the quality of the output signal **412**. An IIR filter continues to respond indefinitely, usually by decaying. In practice, the impulse response of IIR filters usually approaches zero and can be neglected past a certain point. The sound quality maximization unit **400** may result in the output signal **412** having a sound quality approaching the target sound quality wanted by the user. In other words, the sound quality is maximized for a particular listener according to his preferences.

The sound quality maximization unit **400** may be used with any kind of audio algorithm, not just equalizers. The sound quality maximization unit **400** may compute the parameters for any kind of algorithm that enhances the quality of the output signal **412**.

FIG. **5** is a block diagram of a computing device **500** for adaptive signal customization. For example, the computing device **500** may be part of a laptop, tablet, smart phone, or any other suitable electronic device. The computing device **500** may include a processor **502** configured to execute stored instructions. The computing device **500** may include memory **504** configured to store instructions executable by the processor **502**. The processor **502** may be coupled to the memory **504** by a bus **506**. The processor **502** may be a single core processor, a multi-core processor, a computing cluster, or any number of other configurations. The processor **502** may be implemented as a Complex Instruction Set Computer (CISC) processor, a Reduced Instruction Set Computer (RISC) processor, x86 instruction set compatible processor, or any other microprocessor or processor. In some embodiments, the processor **502** includes dual-core processor(s), dual-core mobile processor(s), or the like.

The memory **504** may include random access memory (e.g., SRAM, DRAM, zero capacitor RAM, SONOS, eDRAM, EDO RAM, DDR RAM, RRAM, PRAM, etc.), read only memory (e.g., Mask ROM, PROM, EPROM, EEPROM, etc.), flash memory, or any other suitable memory system. The memory **504** can be used to store data and computer-readable instructions that, when executed by the processor **502**, direct the processor **502** to perform various operations in accordance with embodiments described herein.

The computing device **500** may also include storage **508**. The storage **508** is a physical memory device such as a hard drive, an optical drive, a flash drive, an array of drives, or any combinations thereof. The storage **508** may store data such as input audio signals, filter parameters, among other types of data. The storage **508** may also store programming code such as device drivers, software applications, operating systems, and the like. The programming code stored by the storage **508** may be executed by the processor **502** or any other processors that may be included in the computing device **500**.

The computing device **500** may also include an input/output (I/O) device interface **510** configured to connect the computing device **500** to one or more I/O devices **512**. For example, the I/O devices **512** may include a printer, a scanner, a keyboard, and a pointing device such as a mouse, touchpad, or touchscreen, among others. The I/O devices **512** may be built-in components of the computing device **500**, or may be devices that are externally connected to the computing device **500**.

The computing device **500** may further include an exciter device **200**. The exciter device **200** may be the device described with respect to FIG. **2**. The exciter device **200** may include a PCB **216**. The PCB **216** may be coupled to the processor **502** via the bus **506**. In embodiments, the PCB **216** may be coupled to the bus **506** via spring contacts **218** (not shown). The PCB **216** may include an amplifier **514** that amplifies signals that cause the exciter **100** to vibrate.

The processor **502** may execute the instructions stored in memory **504**. For example, the processor **502** may execute the algorithms of the sound quality maximization unit **400** described above with respect to FIG. **4**. For example, the sound quality maximization unit **400** may instruct the processor **502** to subtract the reference signal **402** from the output signal **412** to obtain the spectrum of the computing device **300** including the exciter **100** combined with the spectrum of the acoustic environment **426**.

Communication between various components of the computing device **500** may be accomplished via one or more busses **506**. At least one of the busses **506** may be a D-PHY bus, a Mobile Industry Processor Interface (MIPI) D-PHY bus, or an M-PHY bus, or any other suitable bus.

The bus architecture shown in FIG. **5** is just one example of a bus architecture that may be used with the techniques disclosed herein. In some examples, the bus **506** may be a single bus that couples all of the components of the computing device **500** according to a particular communication protocol. Furthermore, the computing device **500** may also include any suitable number of busses **506** of varying types, which may use different communication protocols to couple specific components of the computing device **500** according to the design considerations of a particular implementation.

The block diagram of FIG. **5** is not intended to indicate that the computing device **500** is to include all of the components shown. Rather, the computing device **500** can include fewer or additional components not shown in FIG. **5**, depending on the details of the specific implementation. Furthermore, any of the functionalities of the processor **502** may be partially, or entirely, implemented in hardware and/or by a processor. For example, the functionality may be implemented in any combination of Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), logic circuits, and the like. In addition, embodiments of the present techniques can be implemented in any suitable electronic device, including ultra-compact form factor devices, such as System-On-a-Chip (SOC), and multi-chip modules.

FIG. **6** is a process flow diagram of a method **600** for the adaptive customization of an audio signal. The method **600** may be implemented by the computing device shown in FIG. **5**. The method **600** may include blocks **602**-**612**. At block **602**, vibration may be transmitted to an external surface using an exciter **100**. The vibration of the external surface may cause a change in the quality of an output signal **412**, e.g., the vibration may render bass frequencies more audible.

At block **604**, with the equalizer functioning as an FIR filter, an input audio signal **404** may be compared to the output audio signal **412**. At block **606**, a spectrum may be calculated based on the comparison of the input and output audio signals. At block **608**, a change in a quality indicator **428** may be input. At block **610**, FIR taps may be calculated such that the FIR filter has a frequency response that is the inverse of the spectrum of the computing device **400** including the exciter **100** combined with the spectrum of the acoustic environment **426**. The calculation of the FIR taps at block **610** may take into consideration the change in the quality indicator **428** input at block **608**. At block **612**, the calculated FIR taps may be applied to the equalizer **422**. Blocks **602**-**612** may be repeated with the equalizer functioning as an IIR filter alone or in combination with the FIR filter. As a result, the output signal **412** may have a sound quality approaching the target sound quality wanted by the user. If a change in quality indicator **428** is not input at block **608**, the spectrum of the output signal **412** may be flat, i.e., the amplitude of all frequency bands from 20 Hz to 20 kHz will be approximately equal.

The process flow diagram of FIG. **6** is not intended to indicate that the method **600** is to include all of the blocks shown. Further, the method **600** may include any number of additional blocks not shown in FIG. **6**, depending on the details of the specific implementation.

FIG. **7** is a block diagram showing a medium **700** that contains logic for the adaptive customization of an audio signal. The medium **700** may be a non-transitory computer-readable medium that stores code that can be accessed by a processor **702** via a bus **704**. For example, the computer-readable medium **700** can be a volatile or non-volatile data storage device. The medium **700** can also be a logic unit, such as an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), or an arrangement of logic gates implemented in one or more integrated circuits, for example.

The medium **700** may include modules **706**-**714** configured to perform the techniques described herein. With the equalizer functioning as an FIR filter, a signal comparator **706** may be configured to compare input and output audio signals of the computing device **500**. The exciter included in the computing device may transmit vibration to an external surface to change a quality of the output audio signal. A spectrum calculator **708** may be configured to calculate a spectrum of the computing device including the exciter combined with the spectrum of the acoustic environment. A change inputter **710** may be configured to input a change in a quality indicator. An FIR taps calculator **712** may be configured to calculate FIR taps such that the FIR filter has a frequency response that is the inverse of the spectrum of the audio device that includes the exciter combined with the spectrum of the acoustic environment. When calculating the FIR taps, the FIR taps calculator **712** may be configured to consider the change in quality indicator input by the change inputter **710**. A FIR taps applier **714** may be configured to apply the calculated FIR taps to the equalizer **422**. The processor **702** may repeat execution of modules **706**-**714** with the equalizer functioning as an IIR filter alone or in combination with the FIR filter. As a result, the output signal **412** may have a sound quality approaching the target sound quality wanted by the user. However, the spectrum of the output signal **412** may be flat if the change inputter **710** did not input a change in a quality indicator **428**.

The block diagram of FIG. **7** is not intended to indicate that the medium **700** is to include all of the modules shown. Further, the medium **700** may include any number of additional modules not shown in FIG. **7**, depending on the details of the specific implementation.

FIG. **8** is an example according to the present techniques. The graph **800** compares the frequency responses of a laptop with traditional embedded speakers and a laptop with 10 W exciters instead. The frequency responses of the two laptops have not been equalized. The x-axis **802** of the graph **800** is frequency in Hertz. The y-axis **804** is sound pressure level in decibels. Line **806** is the frequency response of the laptop with the exciters. In contrast, line **808** is the frequency response of the laptop with traditional speakers. The laptop including the exciters outperforms the laptop with traditional speakers especially at low frequencies. As indicated by circle **810**, the laptop with the exciters produces bass frequencies three octaves lower than the laptop with the traditional speakers.

EXAMPLES

Example 1 is an exciter device for transmitting vibration to a support. The device includes a housing, wherein a portion of the housing comprises an interior surface and an exterior surface, the interior surface disposed inside the housing and the exterior surface disposed outside the housing; an exciter disposed on the interior surface; and a suspension integrated into the portion of the housing, wherein the suspension is to couple the exciter to the housing.

Example 2 includes the device of example 1, including or excluding optional features. In this example, a printed circuit board comprising an amplifier is disposed on top of the exciter device. Optionally, the device includes a spring contact, wherein a first end of the spring contact is disposed on the printed circuit board and a second end of the spring contact is disposed on a bottom cover housing of an audio device. Optionally, the spring contact electronically couples the housing to the audio device. Optionally, the audio device sits on a support and the exciter transmits a vibration from the audio device to the support. Optionally, the audio device is mechanically decoupled from the exciter. Optionally, the suspension is to mechanically decouple the exciter from the audio device when the housing is coupled with the audio device. Optionally, the housing is removable from the audio device via a retention mechanism.

Example 3 includes the device of any one of examples 1 to 2, including or excluding optional features. In this example, the device includes a plastic foot attached to the suspension. Optionally, the device includes an anti-skid surface attached to the plastic foot.

Example 4 includes the device of any one of examples 1 to 3, including or excluding optional features. In this example, the suspension is a rubber suspension.

Example 5 includes the device of any one of examples 1 to 4, including or excluding optional features. In this example, the suspension is a spring suspension.

Example 6 is an audio device for adaptive signal customization. The device includes an exciter device comprising an exciter to produce vibrations in response to receiving an input audio signal; a memory to store instructions; and a processor communicatively coupled to the memory, wherein when the processor is to execute the instructions, the processor is to: apply a finite impulse response (FIR) filter to the input audio signal; calculate a spectrum of the audio device combined with a spectrum of an acoustic environment surrounding the audio device by comparing the input audio signal to an output audio signal, wherein the output audio signal is determined by the acoustic environment and the audio device; and calculate FIR taps so that the FIR filter has a frequency response that is an inverse of the spectrum of the audio device combined with the spectrum of the acoustic environment.

Example 7 includes the device of example 6, including or excluding optional features. In this example, the FIR taps are calculated to produce the output audio signal via the transmission of vibrations from the exciter device to a support surface.

Example 8 includes the device of any one of examples 6 to 7, including or excluding optional features. In this example, the processor is to transmit the FIR taps to an equalizer of the audio device. Optionally, the equalizer is to flatten a spectrum of the input signal in response to the FIR taps.

Example 9 includes the device of any one of examples 6 to 8, including or excluding optional features. In this example, the processor is to receive a sound quality indicator, wherein the sound quality indicator is to adjust the FIR filter.

Example 10 includes the device of any one of examples 6 to 9, including or excluding optional features. In this example, the processor is to replace the FIR filter by applying an infinite impulse response (IIR) filter to the input audio signal. Optionally, the processor is to apply the FIR filter to the input audio signal in combination with the IIR filter.

Example 11 includes the device of any one of examples 6 to 10, including or excluding optional features. In this example, a sound quality maximization unit is to maximize the sound quality based on sound quality indicators. Optionally, the sound quality maximization unit controls a dynamic range processor in an audio device processing chain to modify a dynamic range of the output audio signal to maximize an output signal quality. Optionally, the sound quality maximization unit controls another processing unit in the audio device processing chain to maximize the output signal quality. Optionally, sound quality indicators include at least one of tonal balance, dynamic range of the audio device, output power of the audio device, phase control, noise, distortion, and frequency response. Optionally, sound quality indicators are to modify a plurality of characteristics of the output audio signal.

Example 12 includes the device of any one of examples 6 to 11, including or excluding optional features. In this example, the spectrum is a frequency spectrum that includes all frequencies possible from the audio device within the acoustic environment.

Example 13 includes the device of any one of examples 6 to 12, including or excluding optional features. In this example, an amplifier is to receive the output signal, process the output signal, and transmit the output signal to the exciter device.

Example 14 is a method for the adaptive customization of an audio signal. The method includes transmitting vibration to an external surface using an exciter in response to receiving an input audio signal; applying a finite impulse response (FIR) filter to an equalizer of an audio device comprising the exciter; comparing the input audio signal to an output audio signal, wherein the output audio signal is determined by an acoustic environment and the audio device comprising the exciter; based on the comparing, calculating a spectrum of the audio device comprising the exciter combined with a spectrum of the acoustic environment; and calculating FIR taps so that the FIR filter has a frequency response that is an inverse of the spectrum of the audio device comprising the exciter combined with the spectrum of the acoustic environment.

Example 15 includes the method of example 14, including or excluding optional features. In this example, the method includes transmitting the FIR taps to the equalizer of the audio device. Optionally, the method includes flattening of a spectrum of the input signal in response to the FIR taps.

Example 16 includes the method of any one of examples 14 to 15, including or excluding optional features. In this example, the method includes receiving a sound quality indicator. Optionally, the method includes adjusting the FIR filter using the sound quality indicator.

Example 17 includes the method of any one of examples 14 to 16, including or excluding optional features. In this example, the method includes replacing the FIR filter by applying an infinite impulse response filter to the input audio signal.

Example 18 includes the method of any one of examples 14 to 17, including or excluding optional features. In this example, the method includes maximizing the sound quality based on sound quality indicators using a sound quality maximization unit. Optionally, the sound quality indicators include at least one of tonal balance, dynamic range of the audio device, output power of the audio device, phase control, noise, distortion, and frequency response. Optionally, the method includes modifying a plurality of characteristics of the output audio signal using sound quality indicators.

Example 19 includes the method of any one of examples 14 to 18, including or excluding optional features. In this example, the spectrum is a frequency spectrum that includes all frequencies possible from the audio device within the acoustic environment.

Example 20 includes the method of any one of examples 14 to 19, including or excluding optional features. In this example, the method includes receiving the output signal, processing the output signal, and transmitting the output signal to the exciter device by an amplifier.

Example 21 is at least one computer-readable medium. The computer-readable medium includes instructions that direct the processor to apply a finite impulse response (FIR) filter to an equalizer of an audio device comprising an exciter; compare an input audio signal to an output audio signal, wherein the output audio signal is determined by an acoustic environment and the audio device comprising the exciter; and wherein the exciter transmits vibrations to an external surface; calculate a spectrum of the audio device comprising the exciter combined with the spectrum of the acoustic environment; and calculate FIR taps so that the FIR filter has a frequency response that is an inverse of the spectrum of the audio device comprising the exciter combined with the spectrum of the acoustic environment.

Example 22 includes the computer-readable medium of example 21, including or excluding optional features. In this example, the computer-readable medium includes instructions to direct the processor to transmit the FIR taps to the equalizer of the audio device. Optionally, the computer-readable medium includes instructions to direct the processor to flatten a spectrum of the input signal in response to the FIR taps.

Example 23 includes the computer-readable medium of any one of examples 21 to 22, including or excluding optional features. In this example, the computer-readable medium includes instructions to direct the processor to receive a sound quality indicator. Optionally, the computer-readable medium includes instructions to direct the processor to adjust the FIR filter using the sound quality indicator.

Example 24 includes the computer-readable medium of any one of examples 21 to 23, including or excluding optional features. In this example, the computer-readable medium includes instructions to direct the processor to replace the FIR filter by applying an infinite impulse response filter to the input audio signal.

Example 25 includes the computer-readable medium of any one of examples 21 to 24, including or excluding optional features. In this example, the computer-readable medium includes instructions to direct the processor to maximize the sound quality based on sound quality indicators. Optionally, the computer-readable medium includes instructions to direct the processor to modify a plurality of characteristics of the output audio signal using the sound quality indicators.

Example 26 includes the computer-readable medium of any one of examples 21 to 25, including or excluding optional features. In this example, the computer-readable medium includes instructions to direct the processor to process the output signal using an amplifier.

Example 27 is an apparatus for the adaptive customization of an audio signal. The apparatus includes a means for transmitting vibration to an external surface using an exciter in response to receiving an input audio signal; a means for applying a finite impulse response (FIR) filter to an equalizer of an audio device comprising the exciter; a means for comparing the input audio signal to an output audio signal, wherein the output audio signal is determined by an acoustic environment and the audio device comprising the exciter; a means for calculating a spectrum of the audio device comprising the exciter combined with a spectrum of the acoustic environment; and a means for calculating FIR taps so that the FIR filter has a frequency response that is an inverse of the spectrum of the audio device comprising the exciter combined with the spectrum of the acoustic environment.

Example 28 includes the apparatus of example 27, including or excluding optional features. In this example, the apparatus includes a means for transmitting the FIR taps to the equalizer of the audio device. Optionally, the apparatus includes a means for flattening a spectrum of the input signal in response to the FIR taps.

Example 29 includes the apparatus of any one of examples 27 to 28, including or excluding optional features. In this example, the apparatus includes a means for receiving a sound quality indicator. Optionally, the apparatus includes a means for adjusting the FIR filter using the sound quality indicator.

Example 30 includes the apparatus of any one of examples 27 to 29, including or excluding optional features. In this example, the apparatus includes a means for replacing the FIR filter by applying an infinite impulse response filter to the input audio signal.

Example 31 includes the apparatus of any one of examples 27 to 30, including or excluding optional features. In this example, the apparatus includes a means for maximizing the sound quality based on sound quality indicators using a sound quality maximization unit.

Some embodiments may be implemented in one or a combination of hardware, firmware, and software. Some embodiments may also be implemented as instructions stored on the tangible, non-transitory, machine-readable medium, which may be read and executed by a computing platform to perform the operations described. In addition, a machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine, e.g., a computer. For example, a machine-readable medium may include read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; flash memory devices; or electrical, optical, acoustical or other form of propagated signals, e.g., carrier waves, infrared signals, digital signals, or the interfaces that transmit and/or receive signals, among others.

An embodiment is an implementation or example. Reference in the specification to "an embodiment," "one embodiment," "some embodiments," "various embodiments," or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least some embodiments, but not necessarily all embodiments, of the present techniques. The various appearances of "an embodiment," "one embodiment," or "some embodiments" are not necessarily all referring to the same embodiments.

Not all components, features, structures, characteristics, etc. described and illustrated herein need be included in a particular embodiment or embodiments. If the specification states a component, feature, structure, or characteristic "may", "might", "can" or "could" be included, for example, that particular component, feature, structure, or characteristic is not required to be included. If the specification or claim refers to "a" or "an" element, that does not mean there is only one of the element. If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

It is to be noted that, although some embodiments have been described in reference to particular implementations, other implementations are possible according to some embodiments. Additionally, the arrangement and/or order of circuit elements or other features illustrated in the drawings and/or described herein need not be arranged in the particular way illustrated and described. Many other arrangements are possible according to some embodiments.

In each system shown in a figure, the elements in some cases may each have a same reference number or a different reference number to suggest that the elements represented could be different and/or similar. However, an element may be flexible enough to have different implementations and work with some or all of the systems shown or described herein. The various elements shown in the figures may be the same or different. Which one is referred to as a first element and which is called a second element is arbitrary.

It is to be understood that specifics in the aforementioned examples may be used anywhere in one or more embodiments. For instance, all optional features of the audio system described above may also be implemented with respect to either of the method or the computer-readable medium described herein. Furthermore, although flow diagrams and/or state diagrams may have been used herein to describe embodiments, the techniques are not limited to those diagrams or to corresponding descriptions herein. For example, flow need not move through each illustrated box or state or in exactly the same order as illustrated and described herein.

The present techniques are not restricted to the particular details listed herein. Indeed, those skilled in the art having the benefit of this disclosure will appreciate that many other variations from the foregoing description and drawings may be made within the scope of the present techniques. Accordingly, it is the following claims including any amendments thereto that define the scope of the present techniques.

What is claimed is:

1. An exciter device for transmitting vibration to a support, comprising:

a housing, wherein a portion of the housing comprises an interior surface and an exterior surface, the interior surface disposed inside the housing and the exterior surface disposed outside the housing;

an exciter disposed on the interior surface, wherein a printed circuit board comprising an amplifier is disposed on top of the exciter device;

a spring contact to electronically couple the housing to an audio device, wherein a first end of the spring contact is disposed on the printed circuit board and a second end of the spring contact is disposed on a bottom cover housing of the audio device, wherein the audio device sits on a support and the exciter transmits a vibration from the audio device to the support; and

a suspension integrated into the portion of the housing, wherein the suspension is to couple the exciter to the housing.

2. The exciter device of claim **1**, wherein the audio device is mechanically decoupled from the exciter.

3. The exciter device of claim **1**, wherein the housing is removable from the audio device via a retention mechanism.

4. The exciter device of claim **1**, comprising a plastic foot attached to the suspension.

5. An audio device for adaptive signal customization, comprising:

an exciter device comprising an exciter to produce vibrations in response to receiving an input audio signal;

a memory to store instructions; and

a processor communicatively coupled to the memory, wherein when the processor is to execute the instructions, the processor is to:

apply a finite impulse response (FIR) filter to the input audio signal;

calculate a spectrum of the audio device combined with a spectrum of an acoustic environment surrounding the audio device by comparing the input audio signal to an output audio signal, wherein the output audio signal is determined by the acoustic environment and the audio device; and

calculate FIR taps so that the FIR filter has a frequency response that is an inverse of the spectrum of the audio device combined with the spectrum of the acoustic environment.

6. The audio device of claim **5**, wherein the processor is to transmit the FIR taps to an equalizer of the audio device.

7. The audio device of claim **6**, wherein the equalizer is to flatten a spectrum of the input signal in response to the FIR taps.

8. The audio device of claim **5**, wherein the processor is to receive a sound quality indicator, wherein the sound quality indicator is to adjust the FIR filter.

9. The audio device of claim **5**, wherein the processor is to replace the FIR filter by applying an infinite impulse response (IIR) filter to the input audio signal.

10. The audio device of claim **9**, wherein the processor is to apply the FIR filter to the input audio signal in combination with the IIR filter.

11. The audio device of claim **5**, wherein a sound quality maximization unit is to maximize the sound quality based on sound quality indicators.

12. The audio device of claim **11**, wherein the sound quality maximization unit controls a dynamic range processor in an audio device processing chain to modify a dynamic range of the output audio signal to maximize an output signal quality.

13. The audio device of claim **11**, wherein the sound quality maximization unit controls another processing unit in the audio device processing chain to maximize the output signal quality.

14. A method for the adaptive customization of an audio signal, comprising:

transmitting vibration to an external surface using an exciter in response to receiving an input audio signal;

applying a finite impulse response (FIR) filter to an equalizer of an audio device comprising the exciter;

comparing the input audio signal to an output audio signal, wherein the output audio signal is determined by an acoustic environment and the audio device comprising the exciter;

based on the comparing, calculating a spectrum of the audio device comprising the exciter combined with a spectrum of the acoustic environment; and

calculating FIR taps so that the FIR filter has a frequency response that is an inverse of the spectrum of the audio device comprising the exciter combined with the spectrum of the acoustic environment.

15. The method of claim **14**, comprising transmitting the FIR taps to the equalizer of the audio device.

16. The method of claim **15**, comprising flattening a spectrum of the input signal in response to the FIR taps.

17. The method of claim **14**, comprising replacing the FIR filter by applying an infinite impulse response filter to the input audio signal.

18. At least one non-transitory computer-readable medium, comprising instructions to direct a processor to:

apply a finite impulse response (FIR) filter to an equalizer of an audio device comprising an exciter;

compare an input audio signal to an output audio signal, wherein the output audio signal is determined by an acoustic environment and the audio device comprising the exciter, and wherein the exciter transmits vibrations to an external surface;

calculate a spectrum of the audio device comprising the exciter combined with the spectrum of the acoustic environment; and

calculate FIR taps so that the FIR filter has a frequency response that is an inverse of the spectrum of the audio device comprising the exciter combined with the spectrum of the acoustic environment.

19. The at least one non-transitory computer-readable medium of claim **18**, comprising instructions to direct the processor to transmit the FIR taps to the equalizer of the audio device.

20. The at least one non-transitory computer-readable medium of claim **19**, comprising instructions to direct the processor to flatten a spectrum of the input signal in response to the FIR taps.

21. The at least one non-transitory computer-readable medium of claim **18**, comprising instructions to direct the processor to receive a sound quality indicator.

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